NAVY EXPERIMENTAL DIVING UNIT

REPORT NO. 2-94

ADVANCED SEAL DELIVERY SYSTEM LIFE SUPPORT PARAMETERS

CDR M. E. KNAFELC

DECEMBER 1993

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The Navy Experimental Diving Unit conducted a literature search of the biomedical factors related to the development of the Advanced SEAL Delivery System (ASDS). This report was intended to assist the Technical Evaluation Board during the initial review of the ASDS design proposals in the areas of atmosphere control and habitability.

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INTRODUCTION

The purpose of this document is to provide a guideline to the Technical Evaluation Board when reviewing the proposals for the Advanced SEAL Delivery System (ASDS). These guidelines are based upon a design that consists of at least 2 habitable compartments. The pilot and navigator will occupy 1 compartment, and its internal pressure will be maintained at 1 ATA. Another habitable compartment will hold the divers, and its inside pressure can be adjusted to permit controlled compression and decompression, or be maintained at a constant 1 ATA. The habitable chambers will be kept dry. Because of safety, environmental and human factors' considerations, it is desirable for the lock-out chamber to be separate from the habitable compartments.

METHODS

A literature review was performed to specifically identify the life support parameters for atmosphere control and habitability within the ASDS.

RESULTS/DISCUSSION

ATMOSPHERE CONTROL

1. Ventilation Requirements

Each manned compartment will have a separate life support loop with adequate ventilation to ensure adequate mixing and CO_2 removal. A blower alarm system is desirable in the event of blower failure in either compartment. For example, the minimal ventilation requirements at various depths are as follows:

Chamber Pressure (ATA)	Ventilation Air Flow (lpm) per person
1.0	33.5
2.8	93.5
5.5	180.0

During lock-in/lock-out (LI/LO) operations, compression and decompression can be accomplished using the diver's underwater breathing apparatus (UBA) or the ASDS built-in-breathing system (BIBS) thus reducing the lockout chamber's ventilation requirements.

The BIBS can be used in conjunction with an emergency breathing system (EBS). A full face mask should be incorporated in the design to provide better comfort for the diver and provide eye protection in the event of atmosphere contamination.

2. Oxygen (O_2) Requirements

The MAXIMUM compartment O_2 limit is 25% (190 mmHg)
The MINIMUM compartment O_2 limit is 19% (145 mmHg)

It is generally assumed that the amount of work within the ASDS would be limited. Oxygen consumption values shown are for compartments at 1 ATA. If the compartment is pressurized the percent of oxygen will remain the same, but the partial pressure of oxygen will increase proportionally to the increase in compartment pressure.

The rate of oxygen consumption varies with work levels. The expected work levels within a confined space is limited; therefore, the oxygen consumptions rates are lower than those encountered normally.

O_2 consumption rate at rest:	0.50 lpm/man
O_2 consumption rate at work:	1.00 lpm/man

An oxygen partial pressure sensor is required to ensure safe O_2 levels. Portable O_2 sensors should be provided in case of primary system failure. The gas sensor will be calibrated prior to each mission. Additional calibrations may be required if the sensor system is unstable over protracted periods of time.

An automatic oxygen addition system with an alarm circuit is advantageous as minimum operator input would be needed to control O_2 levels in each compartment, if the system is working properly. A disadvantage is having to support another set of electronic equipment, which consumes power, requires a redundant system, and additional PMS. A manual O_2 addition system is required as a backup system in the event of the automatic oxygen addition system failure. The O_2 bottle pressure gauges and flow meter are required to provide positive indication of O_2 remaining and flow rate.

3. Carbon Dioxide (CO_2) Limits

The MAXIMUM compartment CO_2 limit is 0.5% Surface Equivalent Value (SEV).

As depth increases, the amount of CO_2 retained in a diver increases. Because of the potential compounding effects of increased blood CO_2 levels on decompression sickness susceptibility, oxygen toxicity, and performance degradation, it is strongly recommended that the compartment CO_2 levels be maintained as low as feasible.

The amount of CO_2 produced is dependent upon the level of activity, which is measured by the oxygen consumption rate. The amount of CO_2 in liters produced for each liter of O_2 consumed is referred to as the respiratory gas exchange ratio (R). The actual R value is dependent upon the level of activity. For example, at rest R is generally about 0.82, and while performing extremely hard work R approaches 1.0. The R value is also affected by diet. Because of these incalculable variances, a conservative R value of 0.9 is recommended for calculating the necessary CO_2 absorbent canister capacity.

CO_2 production at rest: 0.45 lpm/man
CO_2 production at work: 0.90 lpm/man

!MPORTANT: Regardless of the proposed design, the adequacy of the CO_2 scrubber/ventilation system and CO_2 absorbent material must be verified prior to finalizing the design.

Size and capacity desired are the major determinants of the CO_2 scrubber system. The use of lithium hydroxide (LiOH) has an advantage because of its CO_2 absorbing efficiency, which results in lower weight and volume required. Comparing LiOH and sodalime, for the same absorbent capacity, LiOH weighs half that of sodalime. Because LiOH is not readily soluble in water and does not "cake" during use, no special canister bed design is required. In addition, LiOH can absorb CO_2 down to extremely low temperatures. However, due to safety considerations, the use of LiOH in the lock-out chamber is NOT recommended.

The initial canister should have a duration of 12 hrs. The CO_2 scrubber design should allow rapid change out of spent canisters with new absorbent material. The CO_2 absorbent canister should be kept in the pilot chamber.

The LI/LO chamber should have a CO_2 absorbent canister filled with sodalime for emergency use and can be used in conjunction with the emergency breathing system. The duration of the LI/LO canister should be a minimum of 4 hrs.

A carbon dioxide partial pressure sensor is required to ensure safe CO_2 levels within each compartment. Portable CO_2 detectors are required in the event of the primary system failure. Calibration procedures must be established. A minimum calibration of the gas sensor will be performed prior to each mission. Additional calibrations may be required if the sensor systems are demonstrated to be unstable over protracted periods of time.

4. Relative Humidity Requirements

Relative humidity should be maintained between 40 - 60 %

High relative humidity can impact the ASDS's occupants' performance. Low humidity increases the potential for static electricity and increases the likelihood of a fire especially in a hyperbaric environment.

Hardware (i.e., adequate sealed storage of wet gear, sealed closure to the open water) and/or procedural methods must control the water vapor that enters the ASDS through LI/LO procedures. In addition, water vapor is produced by the occupant at a rate of 1.5 liters/day/man, which must be removed by the atmosphere control system.

A relative humidity sensor is necessary to monitor each compartment's humidity. The sensor should remain accurate during changes in compartment pressure.

5. Atmosphere Contaminants

The potential for atmospheric contamination within each compartment can be significant due to the nature of expected evolutions. The use of activated charcoal in the life support loop will significantly reduce contaminant levels in the affected compartment. Procedures should be developed to minimize the introduction of potentially hazardous contaminants into the compartments. The use of activated charcoal, with a surface to mass ratio of 1500 m^2/g, presents a moderate fire hazard.

A Purafil filter can provide odor control of the ASDS atmosphere. The use of Purafil, with a surface to mass ratio of 200 m^2/g, is fire resistant.

6. Depth Control

The divers' compartment must be capable of pressurization to the LI/LO depth. This will allow all divers to adhere to the same decompression profile in order to simplify the mission's logistics. The compartment's gas supply must be of sufficient quantity to allow the chamber to be pressurized to the maximum lock-out depth at least twice.

Decompressing the chamber must be able to be controlled in such a manner to permit decompression stops. Accurate pressure sensors must be installed in each compartment.

HABITABILITY

1. Temperature

NORMAL temperature range is **18 to 23.9° C (65 - 75° F)**
EMERGENCY temperature range is **10 to 32.2° C (50 - 90° F)**

The heating and cooling requirements will depend on the ambient water temperature, as well as the effectiveness of hull insulation. It is assumed that the ASDS operating envelope will be -2.2 to 32.2° C (28 - 90° F). Heat production by the occupants is 5.0×10^5 to 12.6×10^5 J/hr/man (120 - 300 kcal/hr/man).

Temperature sensors are necessary not only for the safety and comfort of the divers, but also to ensure the safe operating temperature for the on-board electronic equipment is not exceeded.

2. <u>Sanitary</u>

The sanitation system may be as simple as several portable toilets to as complex as a built-in sanitation system. Regardless of design, the system must be able to minimize odors and have sufficient capacity to handle bodily wastes.

The approximate quantities of waste material to determine the sanitary system's capacity are:

Urine - 1.6 kg/day/man
Feces - 0.3 kg/day/man

3. <u>Food and Water Requirements</u>

To determine adequate storage facilities for the occupant's food and water, the approximate quantities of food and potable water consumed are:

Water - 2.7 kg/day/man
Food, dry - 0.74 kg/day/man

4. <u>Lighting Requirements</u>

The amount of light required for the safety and efficient performance of personnel is dependent upon the task. Variable lighting control should be considered.

Compartment	Lighting (Lux)
working	150 - 250
dive station area	100 - 110
living	50 - 100
sleeping	20 - 30

5. <u>Communications</u>

The communication system should be a 4-wire, round-robin system that is fully compatible with existing communication systems used with U. S. Navy diving equipment. A sound-powered communication system should back-up any electrically powered system. Through water communications systems that will permit communications between the submersible and its mother ship are recommended.

6. <u>Noise Control</u>

The recommended noise level under normal operations should be **60 - 70 dB** (overall sound level intensity). Excessive noise can be a distraction and irritation to the occupant. Loud noise can also cause temporary and permanent hearing loss.

Brief exposures to noise are expected during LI/LO procedures. Wearing hearing protection during chamber pressurization/depressurization may be required if excessive noise levels are demonstrated.

7. Electrical Safety

In-water electrical hazard thresholds have the potential for being significantly increased due to the decreased resistance provided by the diver's skin when it is in contact with salt water. All electrical systems of the ASDS must comply with the Association of Offshore Diving Contractors *Code of Practice for Safe Use Of Electricity Under Water*, September, 1985. Generally 27 VDC electrical equipment designed for hyperbaric use have performed satisfactorily. Precautions must be taken for any electrical penetrator that may be subject to water intrusion.

8. Emergency Life Support

Due to the nature of the ASDS, a 72 hour/man emergency capability, in addition to the normal life support capacity, is considered adequate for this system. This requirement may vary depending upon the actual intended mission requirement for the ASDS. The emergency battery power shall support all life critical systems, i.e., atmosphere control (O_2 and CO_2 sensors), CO_2 scrubber, communications.

The design of the emergency breathing system (EBS) may be through a boat air system into which the occupant can 'plug-in.' The EBS can be used in conjunction with a man carried CO_2 scrubber to conserve gas.

Thermal support for a casualty would vary with mission, since the temperature in all compartments will approach ambient water temperature over time. Appropriate thermal garments should be staged according to expected water temperature. If operations are to be conducted in extremely warm water, adequate fluids must be stored to prevent heat casualties.

The ASDS design must address the storage area necessary to stow all necessary provisions to support an emergency, as well as support the habitability of long duration missions.

9. Fire Suppression

The choice of fire suppression/extinguishing systems is a balance of compatibility with humans, electrical systems, clean-up, and overall usage. Only systems compatible with humans will be considered.

TABLE 1

Fire Extinguisher Characteristics			
Agent	Compat w/ elect. sys.	Clean-up	Remarks
water	C	C	cheap, easy to handle; good in an oxygen enriched atmosphere
sand	A	B	cheap, slow in application
air foam	B	C	must be directly applied; poor on fires behind obstructions; unknown compatibility in an oxygen enriched environment
dry chem. (NaHCO3, ABC)	A	C	must be directly applied; poor on fires behind obstructions; unknown compatibility in an oxygen enriched environment

10. <u>General Areas of Concern</u>

a. LI/LO procedures must be clearly defined with attention to the ASDS's trim and buoyancy control in order to reduce the possibility of flooding the chamber if the LI/LO employs an air-water interface.

b. Emergency abort capabilities must be delineated. Examples are: emergency signal buoy, in-water recovery system, buoyant ascent capabilities.

c. Preventive measures for propeller fouling such as line cutters attached to the propeller assembly should be addressed.

d. Minimal diver casualty treatment within the ASDS is desirable during operations in remote areas where no treatment facility is immediately available. Minimally, the ASDS should provide sufficient space to pressurize 2 divers and a tender to 60 FSW and have sufficient gas capabilities to complete a U.S.Navy Treatment Table 6 with extensions. Oxygen supply should be available for all divers that go to depth within the chamber. If a closed-circuit oxygen system is being considered for treatment or reducing the decompression obligation, the amount of inert gas that can accumulate in the circuit must be addressed.

e. Compression/decompression controls should be within the pilot chamber with auxiliary controls in the diver's compartment for use during an emergency.

f. The potential for off-gassing must be considered when selecting materials for use within the ASDS.

CONCLUSION

Because the design review for the ASDS is in the preliminary stages, this report addresses, in generalities, the basic life support requirements for the submersible to be use in the ASDS. This document was designed to assist the Technical Evaluation Board in reviewing the competing designs in the area of life support and habitability.

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